UpTempO buoys for Understanding and Prediction

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LONG-TERM GOALS

Our long-term goal is to better understand the evolution of heat content in the upper Arctic Ocean within the Seasonal Ice Zone (**SIZ**), both seasonally during summer warming and fall cooling, and interannually as sea ice retreats and the warming season lengthens. The effort is a contribution to the multi-investigator ONR-sponsored **SIZRS** project (SIZ Reconnaissance Surveys).

OBJECTIVES

Our main objectives are to:

(1) Develop the capability to observe upper ocean warming and cooling using air-deployed ocean drifting buoys.

(2) Better understand the time and space scales of summer warming in the SIZ.

(3) Investigate the relationships between sea ice retreat and upper ocean warming.

APPROACH

Our approach is two-fold:

<u>SIZRS UpTempO buoy deployments</u>: We are working with the Pacific Gyre (**PG**) buoy company (Oceanside, CA) to re-start an air-drop buoy capability that had grown dormant over the past several years. This program was initiated by Professor Peter Niiler at Scripps (UCSD) to drop 200 m long thermistor string buoys ahead of hurricanes in the Gulf of Mexico via Air Force C130 planes, the so-called "hurricane hunters." In recent years, a surplus of buoys developed which coincided with a lack of technological updating. Thus our approach is to work with PG to develop a state-of-the-art air-drop buoy for polar applications. At the same time, we have been working with the US Coast Guard (**USCG**) to deploy these buoys from the Alaskan USCG C130 planes based out of Kodiak, Alaska as part of the SIZRS program.

<u>Scientific analysis of multi-sensor ocean and ice observations</u>: We are working with existing arctic buoy data as well as model output and satellite and in situ data on sea ice and upper ocean temperatures to better understand the time and space scales of upper ocean heating and cooling and

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how these relate to sea ice retreat and advance. The idea here is to develop a measure of where and when we actually need to deploy buoys for climate applications, and how these needs might vary with ice conditions.

WORK COMPLETED

I. Buoy deployments:

Deployments in 2013:

(a) *Buoy air deployment*. PG air-deployed UpTempO buoys (**Figure 1**) consist of a 16" spherical or conical surface hull with electronics, GPS, alkaline batteries for 1.5 years of operation, Iridium antenna, sea level pressure sensor, and sea surface temperature sensor at 0.12 m depth nominal. Hanging down from the hull is a 60 m long string of 12 thermistors at the following nominal depths (in meters below sea level): 2.5, 5, 7.5, 10, 15, 20, 25, 30, 35, 40, 50, 60. There are also 2 or 3 ocean pressure sensors along the string to detect "swing" in the cable owing to current shear (typically forced by surface stress). Some buoys also have a Seabird 37-IM CT cell at 4 m depth. For SIZRS air-deployment, the buoys are specially packaged in a custom box with spooling designed for self-deployment in the ocean.

Initially, the buoy sits rather high on the water surface, until surface waves and spray dissolve the salt blocks that hold the straps and box together (**Figure 2**). At this point the buoy enters the ocean and begins operation when its magnetic switch is activated by a salt-dissolving fastener. Our initial experience from the relatively calm Beaufort Sea indicates that the time from deployment until first data transmission is typically 4-8 hours. Position, sea level pressure, sea surface temperature, and engineering information then begin transmission via Iridium satellite every ten minutes, the buoy string's terminal weight pulls the ocean sensor string down to nominal depth (60 m) and ocean data (temperature, pressure) also begin transmission. We typically re-set sampling within a day (via the Iridium interface) to an hourly schedule.

The USCG approval process for buoy deployment was not completed until early summer, 2013, so we stored the buoys in Kodiak over winter 2012/2013. On August 13, 2013 our first SIZRS UpTempO buoy was air-deployed at 72°N, 150°W (**Figure 3**). The deployment was a success, and another aircraft pass by the location was performed to drop AxCTD (air-deployable expendable CTD) and AxCP (air-deployable expendable current profiler), the former especially useful for intercalibration of buoy and profiler temperature data. We held the second PG buoy for deployment in September, but unfortunately this flight was cancelled, so we held the buoy for deployment in 2014 (see below).

(b) *Buoy ship deployment.* Since USCG air-drop approval only came in spring 2013, over the 2012/2013 winter we ordered other buoys for ship deployment, in order to ensure that at least some buoys would be deployed in summer 2013:

- Three additional PG-manufactured buoys were built using NASA funds with additional sensors beyond the air-deployed models, ie a CT cell at 4 m depth, an additional ocean pressure sensor at 40 m depth, and an anemometer.
    - One of these was successfully deployed via the small research vessel Ukpik just north of the continental shelf break near Prudhoe Bay, Alaska.

- Two more were successfully deployed by the Canadian CG icebreaker Louis St. Laurent as part of the Beaufort Gyre Exploration Project in the Canada Basin.

- Three buoys were built using ONR SIZRS funding by MetOcean Data Systems, Halifax, NS, Canada. These included higher-quality (and more expensive) Seabird thermistors and only extended to 25 m depth for deployment on continental shelves. Shipping was simplified by loading these on the Canadian Coast Guard icebreaker Amundsen for deployment in the eastern Beaufort Sea. Unfortunately, a helicopter accident in summer 2013 brought their field season to an early close before the buoys were deployed, so we stored them over the winter near Toronto and deployed them in 2014 (see below).

Deployments in 2014:

(a) *Buoy air deployment*. Four PG-manufactured UpTempO were air-deployed by the Alaskan USCG in July and August 2014 in the Beaufort Sea at 72N and 73N along 140W. These were:

- One 2013 model held from the previous field season
- One 2014 model with spherical hull
- Two 2014 models with a new conical hull.

Many arctic buoys have transitioned to conical hulls (eg, the Ice-Tethered Profiler) in order to avoid a fairly common situation in which ice floes over-ride the hull, which prevents satellite data transmission. The conical shape enhances upward hull motion when ice floes converge. Two buoys were deployed in July and two more in August. In the final deployment, a semi-hard landing onto the ocean occurred owing to late parachute deployment (it was partially deployed when the box hit the water). In future deployments, we plan to deploy at several hundred feet higher altitude to avoid this situation. All buoys deployed successfully (including the final one) and sent data via Iridium satellite. We did have some sensor pod leakage issues, leading to significant drop-outs in our data stream. The cause was diagnosed as a bad seal between the Delrin plastic pod housing and the thermistor epoxy potting.

(b) *Buoy ship deployment.* Three Metocean-manufactured UpTempO buoys were ship-deployed by the Canadian Coast Guard icebreaker Amundsen in August 2014 in the far eastern Beaufort Sea, on the continental shelf west of Banks Island. All deployments were successful.

<u>II. Scientific analysis of ocean and ice observations:</u>

(a) *SST analysis*: As a first step in our analysis of sea surface temperature (**SST**) patterns in the Arctic Ocean, we have collected gridded fields from three sources: (i) the "Reynolds" a.k.a. OIv.2 NOAA product, (ii) the high resolution MUR product available from JPL's PODAAC = Physical Oceanography Distributed Active Archive Center, and (iii) output from our colleague Dr. Jinlun Zhang's coupled ice-ocean arctic model "**PIOMAS**" = Parallel Ice Ocean Modeling and Assimilation System. Using these fields, we have started to investigate spatial and temporal patterns of correlation and their relationship with sea ice retreat.

(b) *Sea ice analysis*: We expect that the amplitude and patterns of upper ocean heating responds to the time history of sea ice retreat in each summer. As such, we have collected a variety of gridded sea ice

fields for analysis: (i) NSIDC's passive microwave "near-real time" ice concentration product, (ii) NSIDC's higher resolution **MASIE** = Multisensor Arctic Sea Ice Extent product, and (iii) output from the PIOMAS model. Using these fields, we have begun to investigate the spatial and temporal patterns of sea ice retreat, with a special focus on the past 7 years (2007-2013).

RESULTS

I. Initial analysis of buoy data:

Analysis of SIZRS UpTempO buoy data is ongoing. **Figure 4** shows good but not exact agreement between buoy observations and the widely used NOAA OIv2 (a.k.a. "Reynolds") SST field. A major goal of the overall UpTempO buoy program is to improve these fields by increasing the quantity and quality of in situ observations. The figure indicates potentially very interesting and useful information about SSTs in the Marginal Ice Zone, as warm surface temperature episodes are noted when the buoy temporarily exits the sea ice pack.

II. Analysis of gridded SST fields:

Figure 5 shows preliminary analysis of correlation in Reynolds SST fields. The upper two panels show r^2 correlation for a point over the Chukchi Borderland (left) and in the Chukchi Sea (right) over the month of September. The analysis indicates longer correlation length scales for the more southern location, where warming starts earlier and warm Pacific Water flows. Zonal correlation in the northern location may be related to the position of the maximum ice edge retreat. The lower two panels show how correlation length scale can vary interannually. Comparison of Reynolds with MUR and PIOMAS SST fields indicates that Reynolds may underestimate the length scales of SST variability, by as much as 100 km relative to these other sources.

III. Patterns of sea ice retreat:

We are interested in the relationship between ice retreat, wind forcing, and ocean warming. In the course of this investigation, we have discovered a previously unnoted behavior of sea ice retreat that occurs to varying extent every summer. **Figure 6** shows an example from summer 2012, where we have simply plotted the daily ice edge (0.15 concentration contour from passive microwave) for each day of summer as a thin black line. Thicker black lines indicate areas where the ice edge is not moving for several days, i.e., it is "loitering" in place. This loitering typically happens for ~3-7 days in any one location, but does not happen synchronously over the entire ice edge. Analysis of multiple summers indicates that some areas are more prone to loitering, e.g., the eastern Beaufort Sea, northern Chukchi Sea, and the Laptev Sea. When there is unusually rapid ice retreat as in summer 2012, an area of minimal loitering is created in the deep basins, as seen in the Canada Basin in Figure 6. Generally about 30% of the seasonal ice zone experiences some loitering during the summer. Documentation and explanation of this phenomenon is the subject of a paper in preparation for submission to the Journal of Geophysical Research in early 2015 (*M. Steele and W. Ermold, Loitering sea ice retreat in the Arctic Ocean, JGR, in preparation, 2015*).

IMPACT/APPLICATIONS

UpTempO buoys are designed to better observed the warming of the upper ocean that occurs in response to sea ice retreat. Air-deployable SIZRS UpTempO buoys fill a crucial, unique niche in the

over-all program, by providing placement opportunities when icebreakers don't operate and in locations where they may not travel owing to weather or ice conditions. Data from SIZRS buoys are available on the global GTS network for weather forecasting and other purposes. We plan to use SIZRS buoys in combination with other buoys to better understand the time/space scales of variability in upper ocean heat content, in part to create more objective deployment plans for the long-term.

RELATED PROJECTS

We are working with J. Zhang and A. Schweiger as part of ONR's Marginal Ice Zone DRI to improve sea ice – ocean modeling for the Arctic Ocean, with a focus on the MIZ of the Beaufort and Chukchi Seas. UpTempO buoys have been deployed in open water, in the MIZ, and in the main ice pack, and thus provide valuable validation data for the model. Our work described above on the nature of ice retreat is also using output from the model to better understand the physics of this phenomenon.

The SIZRS UpTempO buoy project is part of the over-all SIZRS project, where a group of scientists are working together to better understand the air-sea-ice coupling of the SIZ. The various components of the project are described in a separate progress report by J. Morison.

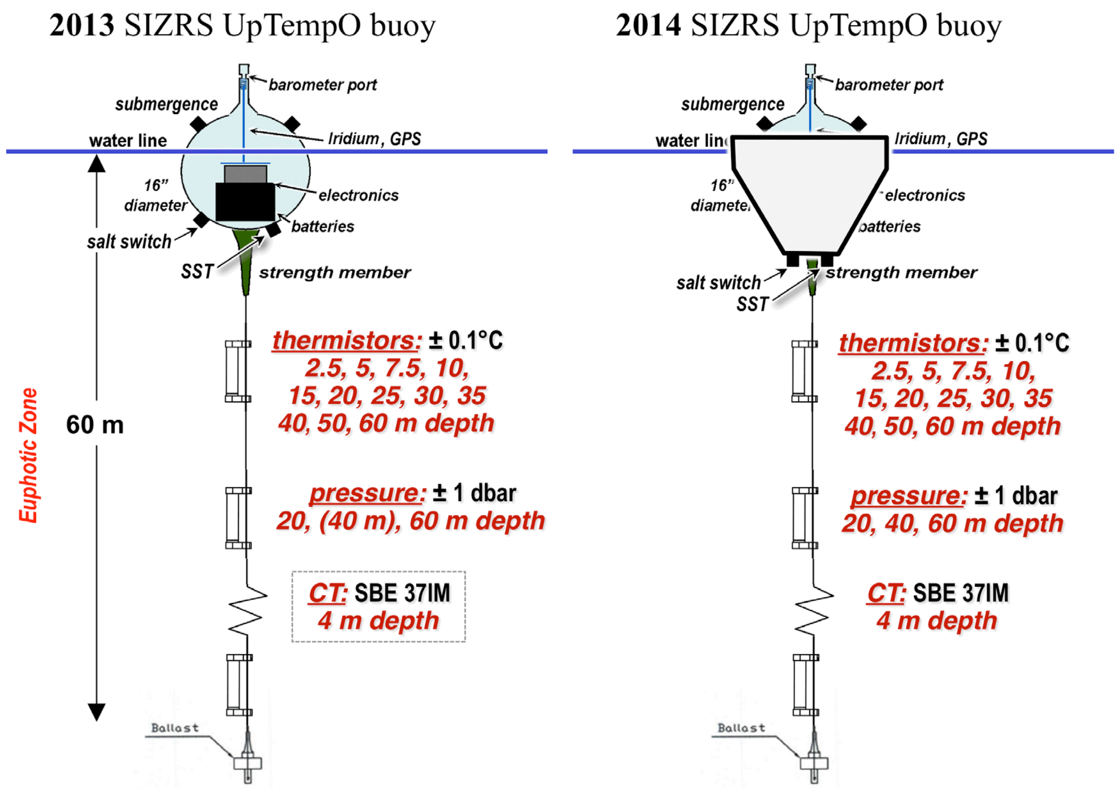

Figure 1. SIZRS UpTempO buoy schematics. These buoys are made for us by Pacific Gyre (PG) Inc. in Oceanside, CA. In 2013, one buoy was air-deployed by the US Coast Guard. Three more PG buoys were manufactured and deployed via ships; these had a CT cell (shown) and an anemometer (not shown). In 2014, four PG buoys were air-deployed by the US Coast Guard. One was a 2013 air-deploy model, one was a new 2014 model but with spherical hull, and two were new 2014 models as shown on the right with a conical fairing for better ice resistance.

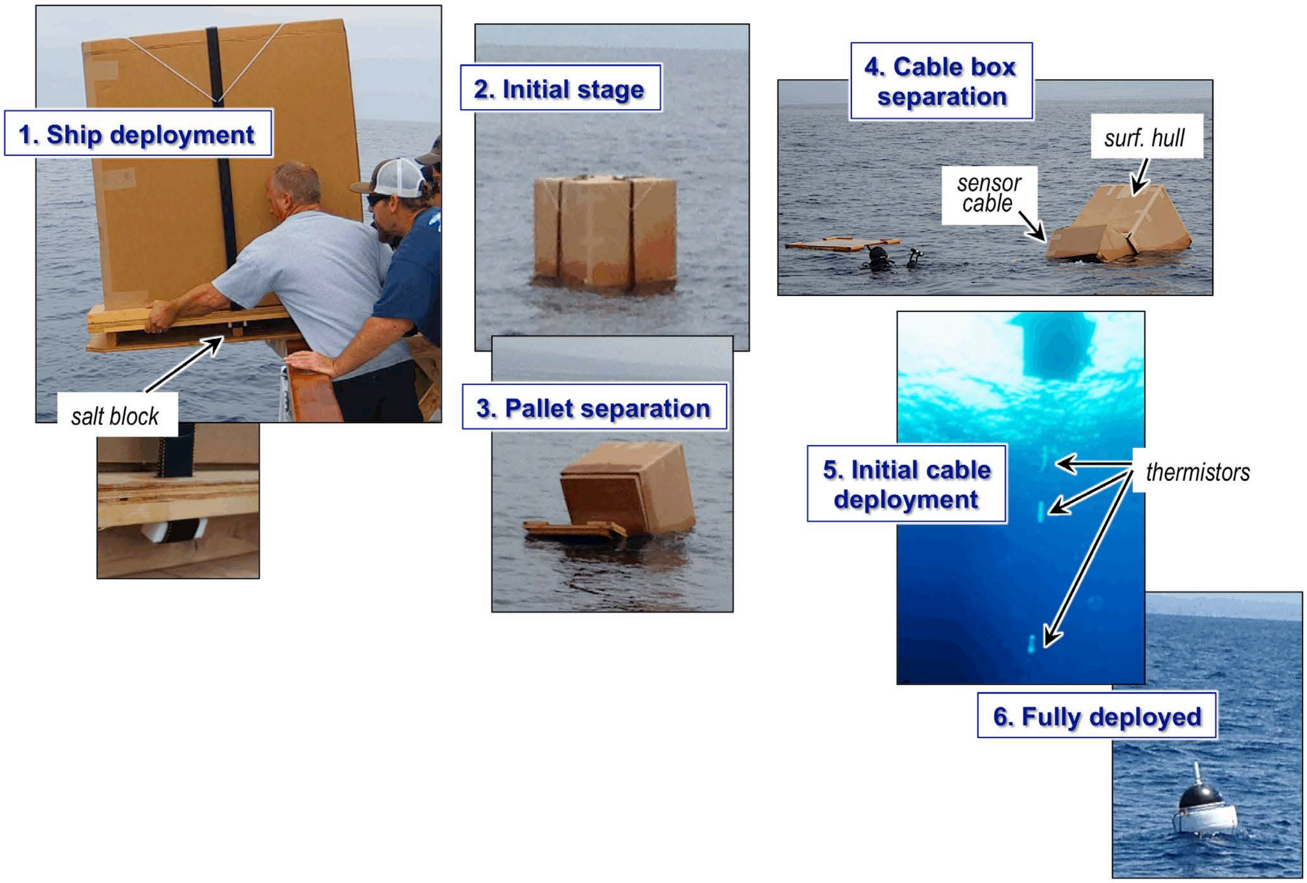

Figure 2. Test deployment of air-drop SIZRS UpTempO buoy configuration in Oceanside, CA, May 2014. A buoy was boxed as for air deployment, but instead pushed off the side of a small fishing boat (step 1). Note white salt blocks that keep the straps secure in the wooden pallet. When these dissolve, the straps loosen and the open-bottomed cardboard box slides off the pallet (steps 2 and 3). The box is held together with only glue and paper tape. The sensor cable is housed in an inner cardboard box that eventually separates and comes apart (step 4), allowing the sensor cable to deploy (step 5). Within an hour of ship deployment, this buoy was fully deployed (step 6) and sending data via satellite. Wind waves were minimal but swell was 1-2 feet. Underwater photos were taken by a scuba diver (visible in step 4 photo near the pallet).

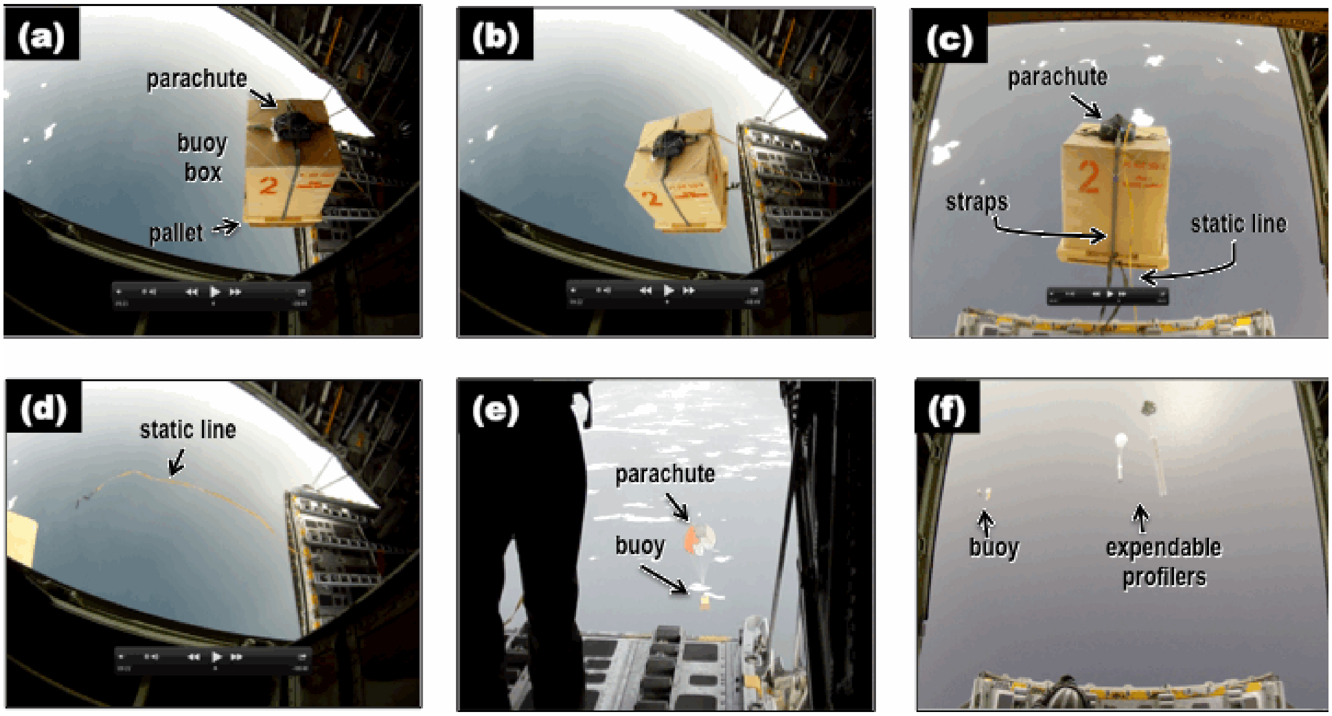

Figure 3. Deployment via C130 aircraft of the first SIZRS UpTempO buoy, August 13, 2013 by the Alaskan United States Coast Guard (USCG) at 72N, 150W. (a) The buoy is packaged in a cardboard box strapped to a wooden pallet (below) and a parachute (above). USCG personnel push the buoy out the aircraft's back door along rollers (a, b, c) when over the target drop location at an altitude of ~400 feet. A static line releases the parachute (c, d, e). (f) Another pass is then performed for co-located deployment of expendable profilers (AxCTD, AxCP). Images from video shot by Dr. I. Rigor, PSC/APL/UW.

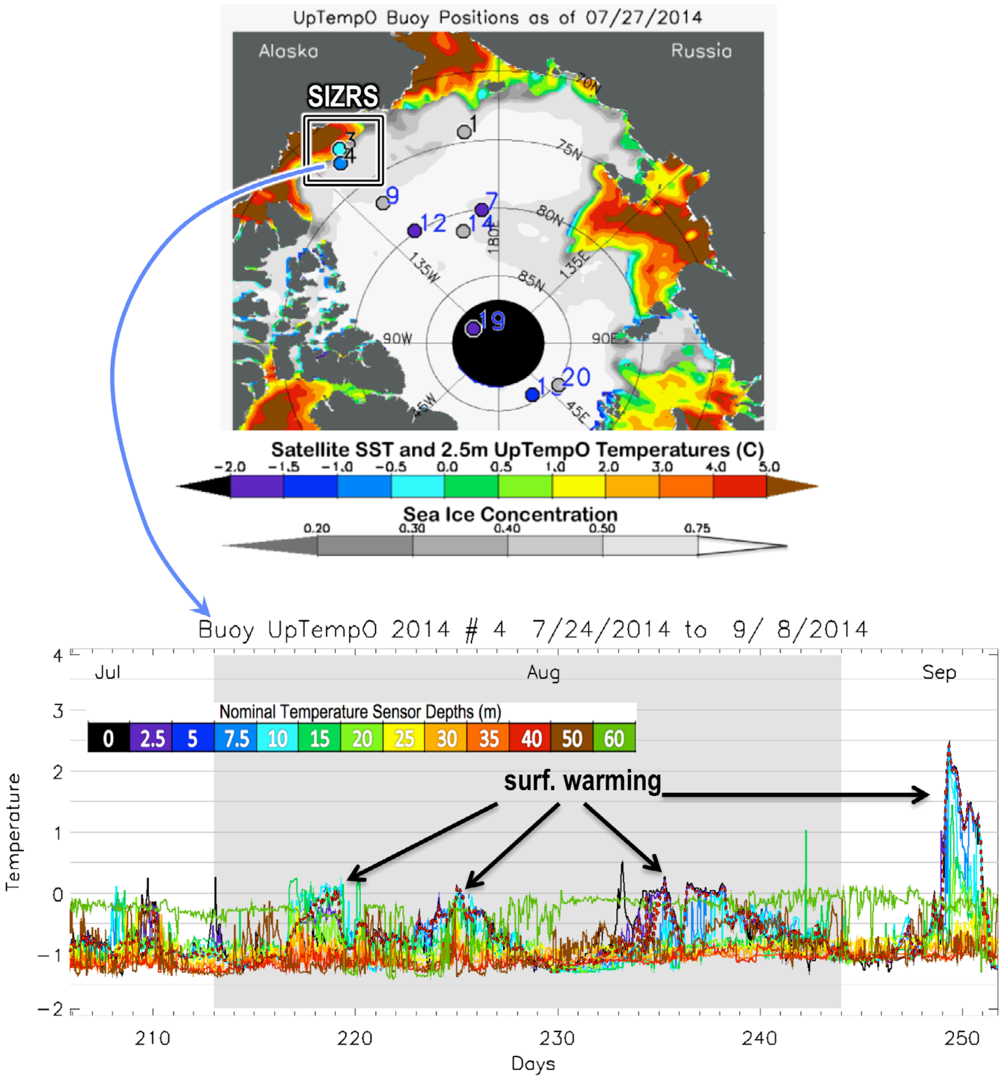

Figure 4. (top) Working UpTempO buoys on July 27, 2014. The first two SIZRS air-deployed buoys are shown (#3 and #4) which were both deployed in July 25 near the Marginal Ice Zone. The blue colors of the dots indicate the SST sensor values, which may be compared to the color contours from NOAA's OIv2 SST analysis on the same color scale. (bottom) Time series from SIZRS UpTempO buoy #4 through mid-September. Conditions were generally near-freezing except at the bottom-most sensor at 60 m which is in the relatively summer Pacific Water. Occasional surface warm excursions indicate transient exit from the ice pack, especially the very warm event in early September.

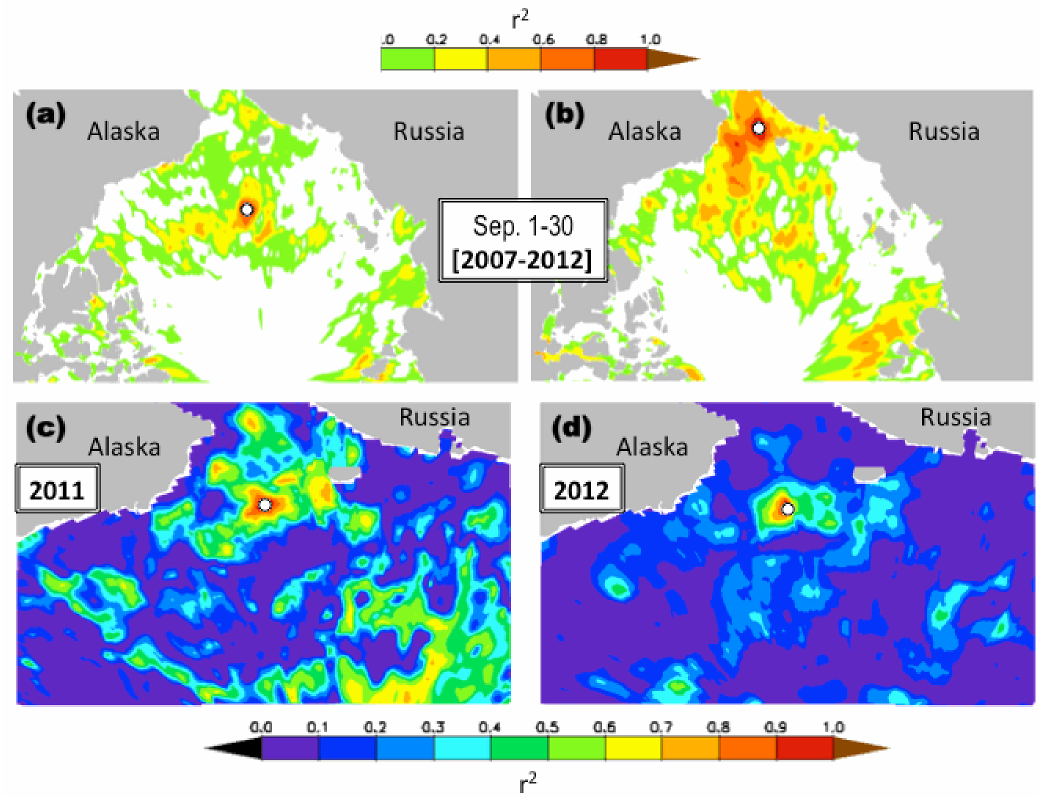

Figure 5. Upper panels: Correlation between the time series of Reynolds SST at a single location (white dot) over the month of September (averaged over 2007-2012) for (a) the Chukchi Borderland and (b) the Chukchi Sea, and all other locations. Lower panels: Same as upper panels, but for two individual years (c) 2011 and (d) 2012 in the northern Chukchi Sea.

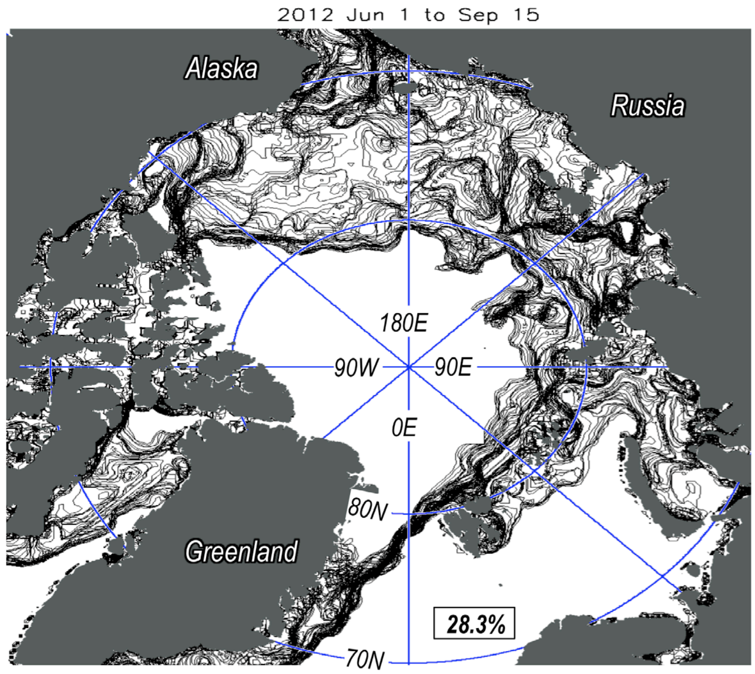

Figure 6. The daily position of the 0.15 ice concentration contour from NSIDC NASA Team algorithm passive microwave data from SSM/I during summer 2012. Each day's ice edge is a thin black line; thicker lines appear where the daily position "loiters" in place over more than one day. Similar analysis for multiple summers indicates that certain areas are prone to "loitering" e.g., the eastern Beaufort, northern Chukchi, and Laptev Seas. The eastern edge of the East Greenland Current is nearly stationary through the summer. Note an area of low loitering in the central Canada Basin, where the ice edge moves quickly northward during late July and August. Loitering periods in the central pack ice are typically ~3-7 days and in summer 2012 covered 28.3% of the seasonal ice zone.